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Geothermal energy potentials in the province of Vojvodina from the aspect of the direct energy utilization

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A B S T R A C T

The interest in increasing the participation of renewable energy sources (RES) in energy production arises with increasing population and growing demands for energy production and consumption, as well as the fact of the limited fossil fuels reserves. RES in the energy balance of any country has their share of energy, socio-economic and environmental benefits. Investment in energy sector in the RES domain enables Vojvodina Province to reduce energy dependence on the fossil fuel market.

From the total RES potential in Vojvodina Province that is 1293 ktoe/year, around 1.7% is located in existing geothermal sources. There are 73 drills with a total capacity of 72.6 MW from which 65 drills are tested positive. Currently, 15 wells are in production, with a total power of 17.7 MW. There are 27 drills that have never been in production and which are perspective, with a total power of 42.8 MW.

The aim of this paper is to perform data analysis of direct geothermal energy utilization according to the water temperature and geothermal fluid flow. According to the results of the analysis recommendations for geothermal energy utilization are given within certain sectors: agriculture (aquaculture and greenhouses), heating of the facilities and pools, industrial applications and balneology.

Contents

Abbreviations: RES, Renewable energy sources; GHP, Geothermal heat pump; GSHP, Ground-source heat pump; BC-2/H, Hydrothermal drill in Becej; BM-1/H, Hydrothermal drill in Backi Monostor; Kl-2/H and Kl-4/H, Hydrothermal drills in Kula; Ho-2/H, Hydrothermal drill in Horgos; Inđ-1/H, Hydrothermal drill in Indjija; Ja-17/H, Hydrothermal drill in Janosik; Kps-1/H, Hydrothermal drill in Kupusina; Kup-1/H, Hydrothermal drill in Kupinovo; Kz-1/H, Kz-2/H and Kz-3/H, Hydrothermal drills in Kanjiza; Lez-1/H, Hydrothermal drill in Lezimir; Mk-1/H, Hydrothermal drill in Mokrin; NS-1/H, Hydrothermal drill in Novi Sad; Pb-1/H and Pb-3/H, Hydrothermal drills in Prigrevica banja; Pj-1/H, Hydrothermal drill in Palic (Palicko jezero); So-1/H, Hydrothermal drill in Sonta; Sr-1/H, Hydrothermal drill in Srbobran; Te-1/H and Te-2/H, Hydrothermal drills in Temerin; Vbc-1/H, Hydrothermal drill in Vrbica; VS-1/H, Hydrothermal drill in Vrbas

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1. Introduction

The primary goal of every society is rational energy utilization. This goal can be achieved by increasing energy efficiency of existing and/or by adequate design of new energy systems that run on fossil fuels, and/or by application of renewable energy sources (RES), so-called clean technologies, with respect to energy, economic and environmental quality indicators during designing, operating and maintenance of the power plants.

The share of RES in energy balance varies in the world, and in general according to available information it is a very small portion compared to the RES potential. The share of geothermal energy is even less, except in a few states where it reached 10% or more [1].

The key recommendation of the European Conference on renewable energy was that the European Union should set a new medium-term target: renewable sources should satisfy at least 20% of energy consumption by the year 2020 [2].

Energy issues and policies have been concerned mainly with increasing the supply of energy. Countries around the world have considered the sufficient production and consumption of energy as one of their main challenges. Modern economies are energy dependent. The provision of sufficient energy has been perceived as a central problem. Energy availability and consumption have been so important a consideration to economies worldwide that the magnitude of energy consumed per capita has become one of the key indicators of modernization and progress in a given country. Attention has begun to shift towards a more balanced perspective, including concerns related both to demand-side and energy consumption patterns. Either way, there is no escaping of the fact that the use of energy is a necessary and vital component of development [3].

The majority of energy produced in the world today is obtained from fossil fuels, i.e. coal, petroleum, natural gas, and nuclear energy. In addition, sustainable and environmentally friendly resources, such as hydro, geothermal, solar, and wind energy and biomass, are also utilized. With increasing awareness of the detrimental effects of the burning of fossil fuels on the environment, there has been an increasing interest worldwide in using clean and renewable energy sources, such as geothermal energy [4].

Taking into account the energy, economic and environmental benefits obtained from RES utilization, they should play an important role in energy balance of every country.

Geothermal energy, one of the most promising among renewable energy sources, has proven to be reliable, clean and safe, and therefore, its use for power production, and heating and cooling is increasing. It is a power source that produces electricity and heat with minimal environmental impact [4].

Presence of the geothermal enrergy utilization as a subject of discussion in recent literature shows the importance and actuality of the topic.

In Autonomous Province of Vojvodina (Vojvodina Province) as a part of Republic of Serbia, the adoption of binding legal regulations in compliance with the EU directives is currently in progress, will result with implementation of stricter standards regarding environmental protection and a more significant participation of renewable energy sources. Accordingly, the exploitation of geothermal energy sources will gain importance [5].

Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Since then, sustainable development has been receiving increased attention, and the importance of sustainable use of the Earth's natural resources has become increasingly clear.

A specific source of primary energy, utilized widely all around the world, is the heat accumulated in the Earth's crust. Estimated amount of this energy is defined as a total geothermal energy potential. The term geothermal energy refers to the natural Earth heat.

Geothermal energy is one of the energy resources that can be used in a sustainable manner, as well as help to mitigate climate change. The potential of Earth's geothermal resources is enormous when compared to its use today and to the future energy needs of mankind [6]. It is estimated that the technically feasible electricity generation potential of identified geothermal resources is 240 GWe ($1\ GW = 10^9\ W$), which is only a small fraction of hidden, or as yet unidentified, resources. The most likely direct use potential of lower temperature resources ($<150\ ^\circ C$) is 140 EJ/yr ($1\ EJ = 10^{18}\ J$). In comparison, the worldwide installed geothermal electricity generation capacity was about 10 GWe in 2007. The direct geothermal utilization amounted to 330 PJ/yr (1 PJ = 1015 J), according to the International Energy Agency's Geothermal Implementing Agreement in 2008 [7]. About one-third of the direct use is through ground-source heat-pumps. It has been estimated that by 2050 the electrical generation potential may reach 70 GWe and the direct use 5.1 EJ/yr. There is, therefore, ample space for accelerated use of geothermal resources worldwide in the near future [8].

In Europe currently the geothermal energy production takes up a very small share of the total amount of energy derived from the renewable energy sources. Although the electricity production is cost-effective and competitive if we compare it with the conventional power plants, the risks associated with the investment into the geothermal sites still continue to be a limiting factor, and thus the installed power amounts to about 1.124 MWe (for 2007) [9].

The use of the heating energy from the geothermal deposits has been showing a slight increase and is mainly used for heating and balneology. It amounts to 13.6 GW [10]. During the last decade the use of the shallow geothermal resources by using heat pumps has shown an exponential growth of over 670,000 installed units in the EU and 7.6 GW (2007) [11]. The plan is that by the end of 2010 the heating energy derived from the geothermal sources (excluding the heat pumps) reaches 5 GW, and together with the installed capacity for the production of the electricity about 1 GWe [12–16].

Geothermal energy could be a very economical energy, meeting greenhouse heating requirements throughout the year, and leaving only a few very cold days for oil or similar conventional energy sources to provide the necessary back-up. Geothermal energy has proven to be very beneficial for agriculture and other related activities [17].

Total potential of RES in the Vojvodina Province is around 1293 ktoe/year and divided by the sources (Fig. 1) [18]:

- 768 ktoe/year is located in biomass,
- 150 ktoe/year is located in biofuels,
- 3 ktoe/year is located in biogas,
- 65 ktoe/year is located in wind energy,
- 22 ktoe/year is located in geothermal energy,
- 7.7 ktoe/year is located in small hydropower plants,

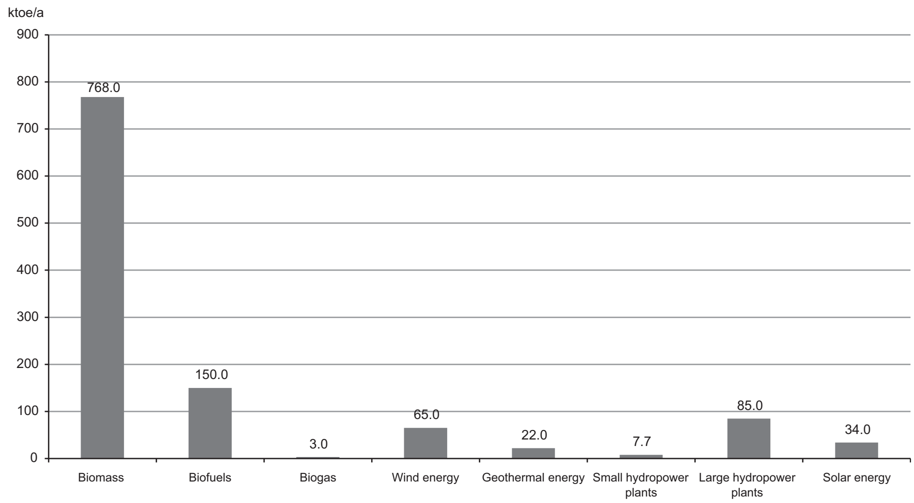

Fig. 1. Participation of different renewable energy sources in total energy potential of Vojvodina Province [18].

- 85 ktoe/year is located in large hydropower plants and
- 34 ktoe/year is located in solar energy.

According to the Energy balance for the year 2010, it is estimated that the total potential of geothermal energy in Vojvodina Province is around 22 ktoe/year, while the amount of heat produced is up to 1800 TJ/year. Planned net energy import in year 2010 was 3.008 Mtoe, which is approximately 21% more than that in 2009, when it was 2.494 Mtoe [18].

The dependence of energy import in year 2010 was around 72.2% which is 2% more than that in 2009 (70.2%). Primary energy for the needs of Vojvodina Province in 2010 is estimated to be 4.216 Mtoe, which is 17% more than the available primary energy estimated for year 2009 (3.607 Mtoe). According to the plan for 2010, the share of RES in the primary energy production is 2.4%, compared to 2009 when it was estimated to be only 1.93%. Considering the above-mentioned data the available potential of geothermal energy in Vojvodina Province should be directed for its use as energy source in energy transformations [18].

The favourable geological conditions constitute the main factor (geological structure, thermal characteristics and chemical composition of water vapour and water; profusion of natural water and drills; size, position and depth of heat reserves in aquifers and rocks of the Earth's crust) on which depends terms of geothermal energy utilization. From the practical point of view the best interests for ranging the possibilities of geothermal energy utilization is certainly not only from the calculation of reserves, but also from the behaviour of geothermal fluid inflow (quantity, temperatures, pressures, chemical composition etc.) that has to be utilized for a longer period of time (usually about 20 years) [1].

The objective of this paper is to perform data analysis of direct geothermal energy utilization according to the water temperature and geothermal fluid flow, as well as to represent current status and future perspectives of direct geothermal energy utilization in Vojvodina Province.

2. Energy potential of geothermal drills in Vojvodina Province

Vojvodina Province is one of the four geothermal regions in the Republic of Serbia (Vojvodina, Macva, Podunavlje and northern Pomoravlje) and represents geologically the most important area, which is located at the southern edge of the Pannonian Basin. Geothermal energy is commonly used in balneology, agriculture and space heating, through heat exchangers and heat pumps [19].

The most common applications of geothermal energy in Vojvodina Province are also the most traditional ones, i.e., balneology and recreation [20].

Complete knowledge about the geothermal potential of drills started to amass after the year 1949. 73 hydrothermal drills (Fig. 2) were bored with a total depth of 62,678.60 m during the period from year 1969 to 1996. The most intensive studies were carried out since the 80s in the last century, when 45 drills were drilled with a total depth of 34.840 feet, which makes about 56% of all drills [21].

The territory of Vojvodina Province belongs to the European geothermal zone that has favourable conditions for the exploration and utilization of geothermal energy. These waters are natural well hot waters and waters in the rocky masses, which can be accessed by drilling boreholes. In Vojvodina four hydrogeological systems were found and systematized. Hydrological systems were tested and their basic characteristics were defined: lithological composition, stratigraphic origin, type and quality of rock-collector, temperature and hydrodynamic conditions, physical and chemical properties of thermal and thermo-mineral waters and associated free gasses.

The first hydrological system has been developed on almost the entire territory of Vojvodina Province. In the deepest parts of northern Banat temperatures reach up to 120 °C. Outlet temperatures at these drills are mostly in the range from 45 to 55 °C. The maximum temperature is 82 °C (Vbc-1/H, Fig. 2). The pressures in earth layers are mainly at the level of hydrostatic pressure or slightly lower and self-outflow profusion is usually in the range from 7 to 13 l/s to a maximum of about 28 l/s (Bc-2/H, Fig. 2). The thermal waters come to the surface with methane gases. The most common values of gas factor are in range from 0.5 to 1.5 m_n^3/m^3, and the largest, single measured value is 2.135 m_n^3/m^3 (Bc-2/H, Fig. 2). Waters, accumulated in this system, are generally NCO_3–Na type of waters, with much less NCO_3–Cl–Na type. The total mineralization is predominantly 2.5–4 g/l and the maximum value is 6.68 g/l (Vbc-1/H, Fig. 2). Salinity is usually 0.3–1.3 g/l and the maximum value is 6.19 g/l (So-1/H, Fig. 2).

The first hydrological system is the most promising system in terms of low temperature water utilization for recreational balneology purposes (around 40 °C) and energy needs (from 40 °C to slightly above 70 °C). This system is most important from the aspect of water supply. Almost all settlements in Vojvodina Province are supplied with underground water as drinking water from the shallow part of this system (about 300 m), where temperature does not exceed 30 °C [21].

Fig. 2. Map of the hydrothermal drills in the Vojvodina Province [21].

The second geological system lies directly below the first one. In the deepest parts of this system the expected temperature is about 160 °C. Output water temperature is around 53 °C and the highest is 79 °C (Ho-2/H, Fig. 2). These waters are examined for hydrocarbons and are negative. Layer pressures are mainly at the hydrostatic level. Profusion of self-outflow is approximately 1.8 l/s and a maximum of 4.2 l/s (Ja-17/H, Fig. 2), based on a dozen drills tested. Gas factor was not measured. These are mainly waters of Cl–HCO_3–Na type. Total mineralization is 7.56 g/l and a maximum of 13.88 g/l (Ja-17/H, Fig. 2). Due to poor collecting quality of these layers, limited propagation and the inability to recharge (inability of re-feeding), small profusion and water reserves, increased mineralization with high content of harmful and toxic components, the main goal is to use these waters in a specific way, primarily in balneology [21].

The third hydrological system lies below the second and partly below the first one. Temperatures in the reservoir rocks reach up to 160 °C and in the deeper parts of the system go possibly up to 175 °C. The average water temperature at the surface of geothermal drills is 46 °C and the highest is 72 °C (Kps-1/H, Fig. 2). In some parts of Backa and Srem (regions of Vojvodina Province), where a hydrodynamic connection with the first and second systems exists, pressures are at hydrostatic levels [21].

In parts of southern and central Banat (region of Vojvodina Province), where hydrodynamic connections are difficult or do not exist, pressures are elevated. In the southern and central Banat pressures are elevated from 120% to 160%, and in central and northern Backa, and northern Banat from 120% to 140%. Average profusion of drills is 5.6 l/s and the maximum is 25 l/s (Pb-3/H, Fig. 2). Gas factor is low and in ranges from 0.009 m_n^3/m^3 (NS-1/H, Fig. 2) to 0.535 m_n^3/m^3 (Pb-1/H, Fig. 2). The waters of this system are aggressive to metals and concrete, have a particularly high mineralization and are very unfavourable for utilization. However, because of the high content of iodine, fluorine, bromine, strontium hydrogen sulphide, metaboric and metasilicic acids and other compounds, they may be suitable for use for balneological purposes [21].

Fourth hydrogeological system is the least researched. According to a previous research, the temperature range up to 200 °C in this system. Average outlet temperature is 49 °C and the highest is 73 °C (BM-1/H, Fig. 2). The pressures in the aquifers are at the hydrostatic level in areas where this system is connected to the surface, and in isolated areas have elevated pressure values. Average profusion of drills is 9.1 l/s and the maximum is 41.7 l/s (Kup-1/H, Fig. 2). Gas factor is low, around 0.006 m_n^3/m^3 (Kup-1/H, Fig. 2) and 0.377 m_n^3/m^3 (Indi-1/H). Measurements were performed only on these two drills. Geothermal water is Cl–Na type, rarely Ca and only in some cases the NCO_3 type of water. The total water mineralization varies in a very wide range from 0.6 to 26.98 g/l (Lez-1/H and Te-2/H, Fig. 2), and salinity varies within the limits from 0.02 to 25.94 g/l [21].

Geothermal waters of the fourth geothermal systems have a convenient chemical composition, and are suitable for use in balneology and energy field (especially waters from southern and eastern Srem). They have good profusion and favourable temperatures and in some cases are suitable for water supply.

2.1. Chemical characteristics of geothermal water in Vojvodina Province

Groundwater in the region of Vojvodina Province, from depths greater than 400–500 m, can be characterized as mineral, with rare exceptions, since they contain more than 1 g of soluble minerals in 1 l of water, and have a temperature higher than 20 °C. Dissolved gasses are often present in mineral waters. The most frequent gas is methane, which is present in amounts from 0.5 to 1.5 m^3/m^3 water. Other gases, like CO_2, H_2S and N_2, are present in small amounts or completely absent. Because of the danger of methane accumulation and explosion, if the water is used indoors, the degassing is performed before using this water.

Ionic composition of water can be bound by certain regularities. As a rule, waters of Pliocene and Upper Pontian age belong to CO_3–Na type, waters of Miocene age to Cl–Na type, and waters

Table 1
Average and maximum concentrations of chemical constituents of geothermal waters [21].

Parameter	Average content (mg/dm^3)	Maximum content mg/dm^3	Content in Vojvodina Province (mg/dm^3)
Mineralization	1000–10,000	360.000	650–7270
Chloride	100–1000	260.000	7–2447
Sodium	100–1000	87.000	100–2450
Sulphate	50–500	84.000	0–280
Calcium	10–100	65.000	2–205
Magnesium	1–10	40.000	0.15–124
Potassium	50–140	30.000	14.2–70
Aluminium	0.5–5	7.200	–
Iron	1–10	4.600	–
SiO_2	50–500	1.060	0–10
Ammoniac	0.5	1.050	0.4–60
CO_2	0.5–5	500	–
Lead	0.5–5	110	0–0.08

Table 2
Significant and relevant characteristics of the geothermal waters [21].

Drills are mainly self-outflow operated and the most frequent water profusion is	(10–20)l/s		
Most frequent outflow temperature is	(40–60)°C		
Geothermal gradients are	(4.5–7.5)°C/100 m		
Nearly all waters contain certain quantities of gasses	Mostly methane		
Waters contain dissolved minerals	(0.42–13.94)g/l		
Mineral contents in drills bored for oil and gas is	(0.40–40.18)g/l		
Drilled	73 Hydrothermal drills	Positive:	65 Drills
Deepest	2520 m	Vrbica, Banat	82 °C at depth (1749–1854)m
Shallowest	305.5 m	Novi Sad	25 °C

from the Lower Pontian collectors belong to the transitional type of Cl–HCO_3–Na. The waters from the older formations belong to mixed type of water, depending on hydraulic connection of the certain formations.

From macro components the following ions dominate in water composition: Na^{1+}, K^{1+}, Ca^{1+}, Mg^{2+}, Cl^{1-}, SO_4^{2-} and HCO_3^{2-}. From micro components iodine, bromine, strontium, lithium, fluorine, etc. are present in water. The presence of organic matter is very strong in the first hydrogeological system, especially humic substances, which in most cases lead to yellowish colour appearance. This is particularly evident when this water is used in swimming pool.

Most of the mineral waters contain components that have an active effect on the human body. The most common are iodine waters (iodine content is up to 20 mg/l). In addition to iodine, waters often contain bromine (up to 500 mg/l), fluorine (up to 11 mg/l), strontium (up to 180 mg/l), metasilicon acid (up to 50 mg/l) and metaboric acid (up to 400 mg/l). Some of these types of water are used as medicinal water in spas (spa "Junaković", spa "Kanjiža", spa "Rusanda", etc.). From undesirable substances that can be present in these waters in Vojvodina Province phenols usually occur, but rarely at unacceptable levels.

In practice, thermal waters of HCO_3–Na type and general mineralization to 6.4 g/l are used for energy and non-energy purposes. Problems like minor corrosion on the drill heads and rare and insignificant phenomenon of incrustation on the walls of pipelines are resolved easily. Deposition and storage of used mineral water is carried out through surface recipients, rivers and canals. To this date, there are no observed adverse effects on the ecosystem, although organized and systematic observation and tests were not performed.

Table 1 provides an overview of the concentration of dissolved chemical elements in geothermal waters [21].

3. Data analysis of hydrothermal systems depending on fluid temperature and profusion

Accumulated geothermal waters, in all hydrogeological systems, are suitable for utilization. However, their temperature, profusion, collector properties, chemical composition, the gas factor and other characteristics give them a different perspective and set specific conditions for their utilization.

From 73 drills, 65 are positive. The deepest drill (see Table 2) is 2520 m deep and is located in Banat, near Vrbice. This drill gives the warmest water at 82 °C and is from 1749 to 1854 m deep. The shallowest drill, 305.5 m deep, gives the water temperature of 25 °C and is located in Novi Sad. The total heat output of hydrothermal drills calculated with cooling at 25 °C, according to data from year 1997, was 85.605 kW, and according to data obtained from Serbian Oil Company "NIS-Naftagas" for year 2005 was 72.579 kW. From 65 positive drills only 15 are used to generate thermal energy. Total capacity of these drills that are consumed is 18.763 kW or 25.85% of the total potential of hydrothermal drills in Vojvodina Province [21].

Since the Vojvodina Province has low temperature drills that are demanding regarding investment cost there is no electricity production, but significant studies are provided concerning that subject.

In Vojvodina Province 24 hydrothermal systems were built on 25 drills. Most of the systems were built during 1984–1988 (18 drills), and the last one was built in 1996. Production and utilization of thermal waters began in 1978, and the systematic registered production since 1990. Production and utilization of thermal waters were in expansion until year 1990 when it started to decline steadily with approximately 1.6 million m^3/year, with constant reduction in number of users and drills operated. To this day about 19 million m^3 of thermal water was produced. In 2003, 73 drills were included in production with 1.07 million m^3 of thermal water produced for 12 users [1].

Only about 30% of the total geothermal potential of all available operating drills was utilized. The total thermal energy of water power and power of all hydrothermal drills is about 55 MW, and the power of all drills which were in production was 23 MW. Possible substitution of fuel oil for operating drills is 10,000 t/year [1].

There are 15 hydrothermal drills that are currently operating, the total power of being 17.7 MW. The largest percentage of drills, about 13.3%, belongs to the class where profusion is from 6 to 8 l/s, and temperature range from 45 to 50 °C. Participation of these geothermal drills based on temperature and profusion range is shown in Table 3 [1].

The total power of these 15 drills is 17.7 MW; the highest percentage, about 20.9% belongs to the drills with profusion from 16 to 18 l/s, and temperatures from 65 to 70 °C. About 16.9% of all drills has profusion from 12 to 14 l/s, and temperatures range from 70 to 75 °C (see Table 4) [1].

Data from year 2002 show that in that year 27.5% of the hydrothermal drills capacity was used. The low percentage of utilization of these drills potential is the result of not adapted

Table 3
Percentage of drills with the range of profusion and temperature [1].

Profusion (l/s)	Temperature range (°C)									
	20–25	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–75
0–2				6.7						
2–4		6.7								
4–6					6.7	6.7				
6–8	6.7	6.7			13.3	6.7				
8–10									6.7	
10–12				6.7		6.7				
12–14										6.7
14–16				6.7						
16–18									6.7	
18–20										

Table 4
Percentage of total power of drills with the range of profusion and temperature [1].

Profusion (l/s)	Temperature range (°C)									
	20–25	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–75
0–2				1.1						
2–4		1.1								
4–6					4.5	5.1				
6–8	1.7	3.4			10.2	6.2				
8–10										
10–12				7.9		11.3				
12–14										16.9
14–16				9.6						
16–18									20.9	
18–20										

Table 5
Percentage of drills with the range of profusion and temperature [1].

Profusion (l/s)	Temperature range (°C)									
	20–25	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–75
0–2										
2–4			9.1							
4–6		9.1	9.1			9.1				
6–8					9.1	9.1				
8–10						27.3				
10–12						9.1		9.1		
12–14										
14–16										
16–18										
18–20										

Table 6
Percentage of total power of drills with the range of profusion and temperature [1].

Profusion (l/s)	Temperature range (°C)									
	20–25	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–75
0–2										
2–4			3.3							
4–6		3.3	3.3			5.8				
6–8					7.5	8.3				
8–10						35.0				
10–12						13.3		20.0		
12–14										
14–16										
16–18										
18-20										

users' system installations or due to lower users' needs in relation to the potential drills exploited [1].

In Vojvodina Province there are hydrothermal drills with built hydrothermal systems, which are currently not in production. There are 11 such drills, the total power of being 12 MW. The largest percentage, about 27.3% of all drills belongs to the class where profusion is from 8 to 10 l/s, and temperature range from 50 to 55 °C. Participation of these geothermal drills based on temperature and flow range is shown in Table 5 [1].

The total power of these 11 drills is 12 MW; the highest percentage, about 35% belongs to the drills with profusion from 8 to 10 l/s, and temperatures in range from 50 to 55 °C. About 20% of all drills has profusion of 10–12 l/s, and temperature range from 60 to 65 °C (see Table 6) [1].

From these 11 drills, 5 drills with profusion of 6.17–11.67 l/s and temperatures from 45 to 63 °C were used for space heating, 4 drills with profusion of 3.5–5.0 l/s and temperatures from 31 to 51 °C were used for recreation purposes (indoor and outdoor swimming pools), and 2 drills with profusion of 8.4 l/s and temperature of 52 °C were used for sanitary water supply [1].

4. Direct geothermal energy utilization

The early history of geothermal direct use has been reviewed for over 25 countries in the Stories from a Heat Earth—Our Geothermal Heritage that documents geothermal use for over 2000 years [22]. Direct use of geothermal energy is one of the oldest, most versatile and also the most common form of utilization of geothermal energy [20]. Geothermal energy, in the form of thermal waters for bathing and medicinal purposes, has been known in the area from prehistoric times [23].

Direct application of geothermal energy can involve a wide variety of end uses, such as space heating and cooling, industry, greenhouses, fish farming, and health spas. It uses mostly existing technology and straight forward engineering. The technology, reliability, economics, and environmental acceptability of direct use of geothermal energy have been demonstrated throughout the world. The main types of direct use are bathing/swimming/balneology, space heating, greenhouses, fish farming, and industry. Direct application can use both high- and low-temperature geothermal resources and is therefore much more widespread in the world than electricity production. Direct application is, however, more site specific for the market, as steam and hot water are rarely transported long distances from the geothermal site. The longest geothermal hot water pipeline in the world is 63 km, in Iceland [24]. The total installed capacity, reported in May 2005 for geothermal direct utilization worldwide, is 28,268 MWt, almost a two-fold increase over the 2000 data, growing at an annual compound rate of 13.3%. The total annual energy use is 273,372 TJ (75,943 GWh), indicating a 43% increase over 2000, and a compound annual growth rate of 7.5% [20].

Based on the possibilities for direct use, depending on the temperature and the type of application, the geothermal sources are divided into:

- heat pumps used for source temperatures of 4 to 38 °C,
- direct use from 38 to 150 °C,
- the ability to produce electricity at a source temperature above 150 °C, although there are examples of use at lower temperature, even at 60 °C.

The direct utilization of geothermal energy includes all applications where no production of electricity occurs. Potentially geothermal energy applications could be divided into [25]:

- application in agriculture (aquaculture and greenhouses),
- heating (rooms, pool),
- industrial applications,
- balneology applications.

The possibilities for direct application of geothermal energy are conditioned by the recommendation that the utilization is limited by their usability at a distance less than 10 km from the source [1,21].

4.1. Aquaculture

In the literature this term is implying fish farming or heating the fish pond by geothermal energy. It is recommended that the temperature of the source is in the range between 20 °C and 66 °C. In addition to water quality as an important factor, each fish has a different temperature at which the optimal development occurs.

Other factors that significantly affect the development of aquaculture, besides water quality, are temperature, dissolved oxygen, nitrogen wastes, alkalinity, water hardness, the portion of carbon dioxide, salinity and the percentage of chlorine and hydrogen sulphide in water.

For specific recommendations concerning the cultivation of certain plant or animal species in this region (especially for some exotic species) the biologists should be consulted [1,21,25].

From drills that are utilized in Vojvodina Province, none are used for aquaculture. Greater number of drills that has never been exploited have a potential for application in aquaculture, when it comes to temperature range. The tests for chemical composition of water are needed to be run [1].

4.2. Greenhouses

The application of geothermal energy for greenhouse heating is one of the most common uses of geothermal sources. Over the years there has been a change in the ways how the greenhouses are constructed and in type of the covering materials that is used:

- glass as the basic material,
- plastic sheeting,
- fibreglass or hard plastic and
- a combination of fibreglass and plastic sheeting or hard plastic.

Supporting structures are slightly different and are made mostly of steel or aluminium. The classification made is based on the type of heating system applied in greenhouse: heating systems with finned tubes, standard heating units, low-temperature heaters, units with fans and systems with seamless tubes [1,21,25].

From drills that are utilized in Vojvodina Province, only one, with a temperature of 63 °C, is used for greenhouse heating. From drills that have never been exploited, at least seven of them with a temperature range from 33 to 57 °C, have a potential for use for this purpose [1].

4.3. Industrial and agricultural processes

Although many industrial and process applications of geothermal energy exist, the world's uses are relatively few [26]. The installed capacity for industrial processes is 533 MWt and the annual energy use 11,745 TJ/year. In the agricultural processes a total of 125 MWt and 1635 TJ/year are being utilized [22]. Geothermal energy in industry is mainly used for drying, evaporation, washing, mining and pasteurization of milk. Drying fruits and vegetables is one of the most widely used applications

of geothermal energy for industrial purposes. The temperature range in which geothermal energy is used is from 30 °C to 180 °C.

The other application of geothermal energy is in mushroom growing. Also the production of bioprotein should be mentioned, because certain quantities of carbon dioxide is used for faster growth of bacteria and microalgae with high protein content of 60–70% compared to 30–36% in soy, and 20% in meat. Here, the cascade application of geothermal energy is possible for geothermal water outlet temperature from 40 °C. For the microalgae production the optimum temperature is around 30–35 °C, and for certain species of fish which will be fed by microalgae, the optimum temperature is in the range from 20 to 30 °C, which increases their growth rate under given conditions. If the flow rate is satisfying, the geothermal energy could be used for protein mass drying [1,21,25].

From drills that are utilized in Vojvodina Province, only one, with a temperature of 45 °C, is used for herb drying. From drills that have never been exploited, five of them with a temperature range from 23 to 45 °C, have a potential for use for this purpose [1].

4.4. Recreational–balneology applications

The purpose of the spa is to provide:

- water treatment using heat and minerals, including mud;
- movement (exercise, massage and fitness);
- medical benefits;
- conditions for a diet (adequate food and drink);
- impact on lifestyle change.

Within some spa resorts the mud with healing properties is used, which can be, depending on its composition, classified: into

- pure mineral–neutral,
- mostly mineral (sea mud)–alkaline and
- sour mud.

Of all the existing applications, the widest application had utilization of geothermal water in balneology purposes, because from 22 installed systems in Vojvodina Province 12 are used for the recreational and balneology purposes [1,21,25].

From drills that are utilized in Vojvodina Province, fourteen of them, with temperature range of 25–65 °C, are used for recreational–balneology purposes. From drills that have never been exploited, nine of them with a temperature range from 27 to 56 °C have a potential for use for this purpose [1].

4.5. Space and district heating

In general the geothermal water for district heating systems is taken directly from low temperature reservoirs. Another way is to use the geothermal water through the heat exchangers to heat up the fresh water. The hot water can be stored in tanks if appropriate. This water then is transmitted to the buildings and can be used for heating and as tap water [27].

In both systems the source of geothermal water along with the associated piping replaces the traditional heating system. For space heating in buildings, one energy source provides hot water preparation, space heating or both combined. Space heating is suitable to be used in areas with undeveloped heating system if there is a geothermal source of adequate capacity.

System of hot water preparation in households includes heat exchanger, circulating pump, storage tank and control system. Hot water preparation requires a higher temperature of heating fluid than that required in space heating. If the chemical composition of geothermal water permits, there is a possibility of direct inflow of the geothermal water in the heater. Recommendations in this case cannot be given without knowing the water composition in that particular location [21].

From drills that are utilized in Vojvodina Province, thirteen of them, with temperature range of 43–65 °C, are used for space and district heating. From drills that have never been exploited, fourteen of them with a temperature range from 51 to 82 °C have a potential for use for this purpose [1].

4.6. Heat pump applications

Geothermal energy has until recently had a considerable economic potential only in areas where thermal water or steam is found concentrated at depths less than 3 km in restricted volumes, analogous to oil in commercial oil reservoirs. This has recently changed with developments in the application of ground source heat pumps using the Earth as a heat source for heating or as a heat sink for cooling, depending on the season. It should be stressed that the heat pumps can be used basically everywhere [24].

Ground-source heat pumps (GSHPs), also known as geothermal heat pumps (GHPs), are an attractive alternative to conventional heating and cooling systems owing to their higher energy utilization efficiency [26].

From drills that are utilized in Vojvodina Province, none has application for heat pumps. From drills that have never been exploited, six of them with temperature range from 54–82 °C have a potential for use for this purpose [1].

5. Current status and future perspectives of direct geothermal energy utilization in Vojvodina Province

Direct-use of geothermal energy is one of the oldest, most versatile and a common form of utilization of geothermal energy [28]. Almost every country has spas and resorts that have swimming pools heated with geothermal water (including balneology), but many allow the water to flow continuously, regardless of use [22]. Geothermal water can successfully replace conventional energy sources. Vojvodina Province has become one of the users of this type of energy recently with favourable hydrogeological conditions [29]. Users of hydrothermal waters in

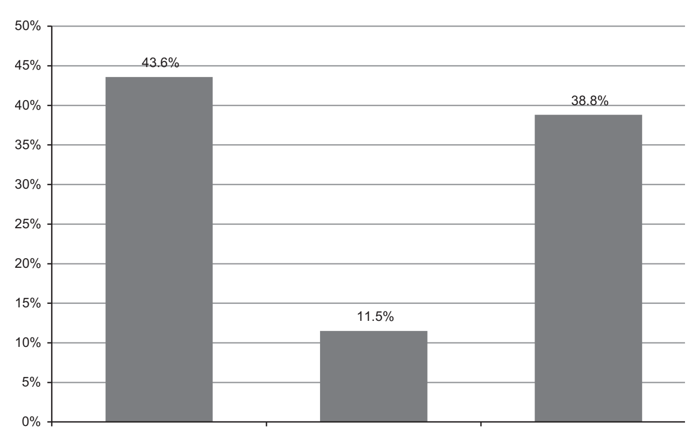

Fig. 3. Utilization posibilities of geothermal energy in Vojvodina Province based on the type of application [21].

Vojvodina Province can be classified into four categories (Fig. 3) by the type of application, use of thermal waters and the amount of water consumed [21]:

- Spas and baths, 43.6%
- Heating facilities, 38.8%
- Technological needs, 11.5%
- Recreation (outdoor and indoor pools), 6.1%.

Using the geothermal sources for energy production is modest. Hydrothermal drills (15 of them) that are currently in production are used in the following purposes, based on temperature range, profusion and gas content [1]:

- for supplying the swimming pools with geothermal water, eight drills are used with temperatures in the range from 25 to 51 °C, profusion from 2.17 to 20 l/s and the gas content of 0–1.26 m^3/m^3.
- for balneology purposes four drills are used with temperatures from 33 to 65 °C, profusion of 5–20.83 l/s and the gas content from 0.082 to 0.554 m^3/m^3.
- For heating the spas, offices and other facilities eight drills are used, temperatures from 45 to 65 °C, profusion of 5.0–20.83 l/s and the gas content of 0.04–1855 m^3/m^3.
- As technological hot water, water is used from two geothermal drills, with temperature around 52 °C, profusion around 8.4 l/s and the gas content 1.15 m^3/m^3.
- For the purpose of herb drying one geothermal drill is used, with a temperature of 45 °C, profusion 7.83 l/s and the gas content 0.04 m^3/m^3.
- For the purpose of greenhouses heating one geothermal drill is used, with a temperature of 63 °C, profusion 11.67 l/s and the gas content 1.44 m^3/m^3.
- For the farm heating three geothermal drills are used, with temperatures from 43 to 51 °C, profusion from 10 to 15.17 l/s and the gas content 0.43–0.5 m^3/m^3.

In Vojvodina Province there are 73 drills of which 65 are tested positive. Technically equipped are 25 drills from which only 15 are still in use and each drill has more than one application. From 15 hydrothermal drills that are currently in the production, 8 of them are used for supplying the swimming pools with geothermal water, 4 for balneology, 8 for space heating, 2 for a technological hot water preparation, 3 for farm heating, 1 for herb drying and 1 for greenhouse heating.

The most important and the largest by the capacity of users of geothermal energy are thermal spas Kanjiza and Junakovic, and sports and recreation centre in Becej. Kanjiza spa uses three drills (Kz-1/H, Kz-2/H and Kz-3/H, Fig. 2). In the winter period Kz-3/H is usually used and in summer Kz-1/H. Hydrothermal water is used for multiple purposes: heating of buildings (low temperature), balneotherapy, recreation and sanitary hot water preparation. Total power of the drills was 4.033 kW. Total installed consumption power is 2.732 kW. Built heat exchanging station with two plate exchangers with a total output heat of 1650 kW meets the needs of the spa when the outside air temperature is not below −5 °C. The spa uses around 110,000 m^3 of thermal water per year [22].

Junakovic spa uses the drill Pb-1/H. Hydrothermal water is used for the same purpose as Kanjiza spa. Total power of the drill is 1.877 kW (according to data obtained from Serbian Oil Company "NIS-Naftagas"). [12] Junakovic spa facility was the first in Vojvodina Province that applied heat pumps for space heating. Total installed consumption power is 1.581 kW. The spa uses approximately 150,000 m^3 of thermal water per year [22].

The next significant multi-user of thermal water (BC-2/H, Fig. 2) is a sports and recreation centre in Becej. Heat capacity of the drill is 3.601 kW and is used for heating of buildings, preparation of sanitary hot water and heating water in the swimming pools. This drill was characterized by a large content of combustible gases that can be used for additional water reheating. The energy of thermal water meets the needs of consumers when the outside air temperature is not below −5 °C. The consumers use up to 100,000 m^3 of thermal water per year [22].

Near Kikinda, thermal water is used for heating pig farms. For drills VS-1/H (Fig. 2) in the Banatsko Veliko Selo and Mk-1/H (Fig. 2) in Mokrin are used. The total heat output of these two drills is 2.368 kW. The energy of thermal water from these drills is used for seasonal, low temperature (air) heating of the farms. The farm in Banatsko Veliko Selo uses around 120,000 m^3 of thermal water per year [22].

Previously, the factories in Kula, fabric factory "Kulski stofovi" and leather factory "Eterna" used drill (Kl-4/H, Fig. 2) or (Kl-2/H, Fig. 2) for their technological needs. Used thermal power amounted to 3.700 kW that is now reduced to the use of drill (Cl-2/H, Fig. 2) in the leather factory "Eterna" with a heat output of 891 kW [22].

Geothermal energy is used for indoor vegetable production. A typical example is the heating of 0.5 ha greenhouses in Srbobran. This property is no longer in use and is therefore suspended from exploitation (Sr-1/H, Fig. 2) [22].

The group's recreation centres were opened in Temerin and Palic and indoor recreational pool in Vrbas. The first two are still in operation and use thermal water from drills Te-1/H and Pj-1/H (Fig. 2), with a total heat power of 2.320 kW [22].

Common to all consumers is to discharge used water into nearby surface water recipients that is not in accordance with environmental requirements and should be reconsidered [1,24].

Currently, in Vojvodina Province the geothermal energy exploitation is dominant in the non-energy sector, even though the primary objective of the exploitation should be to use in energy field for fuels substitution, which would result in fossil fuel preservation and pollution minimization.

Geothermal waters in Vojvodina Province, considering the physical, chemical and geothermal properties, could be used in agriculture for greenhouse heating, in livestock and poultry farms for air heating, in industry as technological hot water, for balneotherapy and in sports and tourist centres, for district heating, for sanitary hot water preparation, in fish farming etc.

In Vojvodina Province, there are 27 hydrothermal drills that have never been exploited, which are promising in terms of both energy production and sanitary hot water preparation. Depending on the thermal waters temperature, and profusion of drills and localities, these 27 drills can be used for the following purposes [1]:

- For the purpose of heating sports and recreation centres, spas, hotels, industrial, residential and other facilities, ten drills with a temperature range between 51 and 82 °C and profusion between 3.30 and 42.84 l/s could be used.
- In spas, sports and recreational centres, for balneology purposes, pool heating and sanitary hot water preparation nine drills with a temperature range from 27 to 56 °C and profusion from 2.70 to 15.70 l/s could be used.
- In agriculture, for greenhouse heating, seven drills could be used with a temperature range from 33 to 57 °C and profusion from 2.50 to 16.65 l/s.
- For heating the livestock and poultry farms and sanitary hot water preparation, four drills with a temperature range from 54 to 57 °C and profusion from 4.70 to 14.66 l/s could be used.

- In factories for low-temperature technological and sanitary hot water needs five drills with a temperature range from 23 to 45 °C and profusion from 2.70 to 17.06 l/s could be used.

From 27 technically equipped hydrothermal drills that have never been exploited, 10 drills could be used for heating, 7 drills in agriculture, 9 drills for recreation, balneology and sanitary hot water preparation, 4 drills for heating the livestock, poultry farms and sanitary hot water preparation, and 5 drills for low-temperature technological and sanitary hot water preparation in factories.

From these, two drills have the potential for electricity production—in Vrbica with a source temperature of 82 °C, profusion 16.70 l/s and thermal power 3.98 MW and the other in Kupinovo with a temperature of 51 °C, profusion 42.84 l/s and heat power 4.01 MW.

Regarding the possibility of using geothermal fluids for space heating, they are still modest, although there is a possibility of utilization of thermal energy for melting snow, where the pipe system is installed in a similar way as for floor heating [1,21].

Nowadays, the average annual geothermal energy production, used mostly in balneology purposes, according to the Oil Company "NIS-Naftagas" is 0.739 Mm^3/year, or 0.0016 Mtoe with decreasing trend in utilization of 20%.

This trend is evident because of the relatively high price of energy obtained from existing drills used for heating and sanitary hot water preparation or because of problems with property rights or extremely high price of thermal energy produced from geothermal water.

The interest of foreign investors, for the construction of new hydrothermal drills has increased recently, especially investors from Hungary.

The drills would be used in order to produce heat for district heating and for electricity generation. The price of electricity obtained in this manner is at least stimulating compared to prices in the EU for electric power produced from geothermal energy [30].

6. Conclusion

Renewable energy sources have their share in the energy balance of almost every country, but not as much as they should have compared to the given energy potential, although allowing the application of clean technologies and pollution reduction, reduce energy dependence on fossil fuel markets and enable the development of new technologies and supporting infrastructure that create new jobs [31].

Geothermal energy has worldwide spread application with its proven technology and abundant resources, and so a significant contribution can be made in the direction of global emission reduction; but using the geothermal sources for energy production is modest. From year 1990 to 2050, the primary energy consumption is expected to increase by 50% according to the most environmentally conscious scenario and by 275% according to the highest growth rate scenario. In the environmental scenario, carbon emissions are expected to decrease slightly from 1990 levels, whereas the high growth-rate scenario leads to a doubling of carbon emissions [32].

Total potential of RES in the Vojvodina Province is around 1293 ktoe/year and is around 22 ktoe/year for geothermal energy.

73 hydrothermal drills are located in Vojvodina Province, and 65 of them are tested positive. The total heat output of hydrothermal drills is 72.579 kW. From all positive drills, 15 are used for thermal energy production. These drills that are under exploitation, with a total capacity of 18.763 kW, represent 25.85% of the total potential of all hydrothermal drills in Vojvodina Province.

Drills are mainly self-outflow operated with water profusion in the range of 10–20 l/s. Most frequent outflow temperature range is 40–60 °C and geothermal gradients are 4.5–7.5 °C/100 m. Almost all hydrothermal waters contain methane.

All users in Vojvodina Province can be classified into four categories by the type of application and use of thermal waters and the amount of water consumed in spas and baths (43.6%), heating facilities (38.8%), technology needs (11.5%), and recreation—as indoor and outdoor swimming pools (6.1%). According to the results of the analysis recommendations for geothermal energy utilization are given within certain sectors: agriculture (aquaculture and greenhouses), heating of the facilities and pools, industrial applications and balneology.

The use of geothermal energy has certain energy, socio-economic and environmental benefits over the use of conventional energy. Geothermal energy is a clean, sustainable energy that can play an important part in a state's energy policy and reduce reliance on imported oil and exposure to the volatile world oil price market. Direct geothermal energy utilization and power plants create new jobs in the field of construction, operation, maintenance and administration. Geothermal energy has helped in reducing air pollution.

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